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Interaction between Solar Wind and Lunar Magnetic Anomalies observed by Kaguya MAP-PACE

Yoshifumi Saito (1), Shoichiro Yokota (1), Takaaki Tanaka (1), Kazushi Asamura (1), Masaki Nishino (1), Tadateru Yamamoto (1), Kota Uemura (1), Hideo Tsunakawa (2), and the KAGUYA MAP Team

(1) Institute of Space and Astronautical Science, STP, Sagamihara, Kanagawa, Japan (saito@stp.isas.jaxa.jp), (2) Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan

It is known that Moon has neither global intrinsic magnetic field nor thick atmosphere. Different from the Earth's case where the intrinsic global magnetic field prevents the solar wind from penetrating into the magnetosphere, solar wind directly impacts the lunar surface. Since the discovery of the lunar crustal magnetic field in 1960s, several papers have been published concerning the interaction between the solar wind and the lunar magnetic anomalies. MAG/ER on Lunar Prospector found heating of the solar wind electrons presumably due to the interaction between the solar wind and the lunar magnetic anomalies and the existence of the mini-magnetosphere was suggested. However, the detailed mechanism of the interaction has been unclear mainly due to the lack of the in-situ observed data of low energy ions. MAgnetic field and Plasma experiment – Plasma energy Angle and Composition Experiment (MAP-PACE) on Kaguya (SELENE) completed its ∼1.5-year observation of the low energy charged particles around the Moon on 10 June, 2009. Kaguya was launched on 14 September 2007 by H2A launch vehicle from Tanegashima Space Center in Japan. Kaguya was inserted into a circular lunar polar orbit of 100km altitude and continued observation for nearly 1.5 years till it impacted the Moon on 10 June 2009. During the last 5 months, the orbit was lowered to ∼50km-altitude between January 2009 and April 2009, and some orbits had further lower perilune altitude of ∼10km after April 2009. MAP-PACE consisted of 4 sensors: ESA (Electron Spectrum Analyzer)-S1, ESA-S2, IMA (Ion Mass Analyzer), and IEA (Ion Energy Analyzer). All the sensors performed quite well as expected from the laboratory experiment carried out before launch. Since each sensor had hemispherical field of view, two electron sensors and two ion sensors that were installed on the spacecraft panels opposite to each other could cover full 3-dimensional phase space of low energy electrons and ions. One of the ion sensors IMA was an energy mass spectrometer. IMA measured mass identified ion energy spectra that had never been obtained at 100km altitude polar orbit around the Moon. When Kaguya flew over South Pole Aitken region, where strong magnetic anomalies exist, solar wind ions reflected by magnetic anomalies were observed. These ions had much higher flux than the solar wind protons scattered at the lunar surface. The magnetically reflected ions had nearly the same energy as the incident solar wind ions while the solar wind protons scattered at the lunar surface had slightly lower energy than the incident solar wind ions. At 100km altitude, when the reflected ions were observed, the simultaneously measured electrons were often heated and the incident solar wind ions were sometimes slightly decelerated. At ∼50km altitude, when the reflected ions were observed, proton scattering at the lunar surface clearly disappeared. It suggests that there exists an area on the lunar surface where solar wind does not impact. At ∼10km altitude, the interaction between the solar wind ions and the lunar magnetic anomalies was remarkable with clear deceleration of the incident solar wind ions and heating of the reflected ions as well as significant heating of the electrons. Calculating velocity moments including density, velocity, temperature of the ions and electrons, we have found that there exists 100km scale regions over strong magnetic anomalies where plasma parameters are quite different from the outside. Solar wind ions observed at 10km altitude show several different behaviors such as deceleration without heating and heating in a limited region inside the magnetic anomalies that may be caused by the magnetic field structure. The deceleration of the solar wind has the same E/q (E : deceleration energy, q: charge) for different species, which constraints the possible mechanisms of the interaction between solar wind and magnetic anomalies.